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Evaluation of X-ray Fluorescence Unit for Detecting Lead in Paint on Military Structures

by
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Despite the toxicity of lead as a pigment in paint, lead-base paint continued to be used in the United States until the mid-1950's. It is more difficult to date the discontinued use of lead-base paints on Army structures in foreign countries because locally procured paints are allowed to contain higher amounts of lead than those purchased in the United States. This situation is causing concern for installation Directorates of Engineering and Housing (DEHs) in Germany.

The objective of this work was to evaluate the x-ray fluorescence (XRF) lead detector to determine its suitability for field use for measuring the lead content of paint on military structures in West Germany. A Princeton Gamma Tech (PGT) XK-3 unit was purchased for evaluation. Field work showed the detector to be durable and reliable. Standardization readings can compensate for the effect of the substrate on the readings. Accurate results can be obtained using a limited number of readings and the unit can detect lead-base paint hidden by layers of non-lead paint. It is recommended that the conclusions of this study be confirmed using other XRF units. It is also recommended that the Army adopt a lead concentration level above which abatement must be accomplished.

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The objective of this work was to evaluate the x-ray fluorescence (XRF) lead detector to determine its suitability for field use for measuring the lead content of paint on military structures in West Germany. A Princeton Gamma Tech (PGT) XK-3 unit was purchased for evaluation. Field work showed the detector to be durable and reliable. Standardization readings can compensate for the effect of the substrate on the readings. Accurate results can be obtained using a limited number of readings and the unit can detect lead-base paint hidden by layers of nonlead paint. It is recommended that the conclusions of this study be confirmed using other XRF units. It is also recommended that the Army adopt a lead concentration level above which abatement must be accomplished.

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FOREWORD

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COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The toxicity of lead as a pigment in paint is well known. This knowledge, however, did not eliminate the use of lead-base paint until recently. In the United States it is assumed that lead-base paints were used in all homes built before 1940.[1] Continued use after that time varied with location. However, it is probable that very little lead pigmented paint was used in housing after the mid-1950's. The military community may or may not have followed this trend. Federal specifications for paint containing lead have been updated as recently as 1965 and have been included as one of the standard paint systems in construction specifications dated as recently as September 1968.[2]

It is very difficult to date the discontinued use of lead-base paints on Army structures in foreign countries. Although all military facilities (both foreign and domestic) must comply with Federal requirements, it is believed that in many cases locally procured paints have been used in family housing in West Germany. Paints purchased from local sources are allowed to contain higher amounts of lead than those purchased in the United States. This situation is causing concern for installation Directorates of Engineering and Housing (DEHs) in Germany.

In 1976 Federal law was enacted to limit the lead content to 0.06 percent lead in the dried paint film for all paints that might be applied to residential structures. The law only applies to paints manufactured since 1977 and does not apply to paints that may have been applied before that date. It was not the intent of the law to require removal or abatement of existing coatings. In order to implement compliance with the law, the Office of the Chief of Engineers issued an Engineer Technical Letter[3] that altered the painting guide specification and identified lead-base paints that were in common use at that time.

The only law that addresses the problem of existing paint containing lead is published in the Federal Register Volume 53, No. 108, dated June 6, 1988. This law requires the use of an "x-ray fluorescence (XRF) analyzer or comparable approved sampling or testing technique" to determine the amount of lead in milligrams per square centimeter (mg/cm^2) of surface. This law was enacted on behalf of the office of Housing and Urban Development (HUD) and is only binding on "public housing assisted under Section 9 of the United States Housing Act of 1937" (bought or built with HUD financing) or HUD-owned properties. The law is not binding on Army facilities but could provide the basis for testing and standardization within the Army. Although the law requires the use of an XRF unit or comparable technique, it does not provide information regarding the appropriate use of the equipment. Specifically, there is no guidance for substrate correction, number of readings to be taken per site, or the number of sites to be tested per wall or per building.

[1] *Lead-Base Paint in Housing* Task Force Report to the Board of Directors (National Institute of Building Sciences [NIBS], February 1988).

[2] Federal Specification (Fed. Spec.) TT-P-104b, *Paint, White Lead and Oil, Exterior, Ready-Mixed White and Light Tints* (1965); Fed. Spec. TT-P-001102b, Paint, Oil: Titanium-Lead-Zinc and Oil, Exterior, Ready-Mixed, White and Light Tints (referenced in CE-250, Guide Specification for Military and Civil Works Construction, *Painting, General*, September 1968).

[3] Engineer Technical Letter (ETL) 1110-1-88, *Engineering and Design, Prohibition on Use of Lead-Based Paint* (Department of the Army, 2 May 1977).

Objective

The objective of this work was to evaluate the XRF lead detector to determine its suitability for field use for measuring the amount of lead in paint films.

Approach

After reviewing a National Institute of Standards and Technology (NIST) evaluation of portable XRF lead detectors[4], a PGT XK-3[*] unit was purchased for evaluation. Initial testing was conducted to determine the unit's accuracy. The unit was then used to determine the amount of lead on building components of a random sampling of the buildings at U.S. troop installations in West Germany. Because inaccuracies in the data were noted and were not explained by the NIST report, additional laboratory work was conducted to verify the effect of substrate material and paint film thickness on the instrument readout.

Scope

Due to funding limitations, only one XRF unit, the PGT XK-3, was evaluated.

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[4] A. Camp and H. Berger, *Evaluation of New Portable X-ray Fluorescent Lead Analyzers for Measuring Lead in Paint*, NBSIR 78-1466 (National Institute of Standards and Technology [NIST], May 1978).

[*] Manufactured by Princeton Gamma-Tech, Inc., 568 Weddell Drive, Suite 1, Sunnyvale, CA 94089.

2 TEST PROCEDURES

Equipment

The PGT XK-3 (Figure 1), costing less than $10,000, comes in a briefcase-size carrying case. It is a hand-held unit containing a radioactive source, a detector, and a liquid crystal display (LCD). A battery pack belt and a 120-volt alternating current (AC) battery charger are included. To determine the lead content of a flat surface, the unit is turned on and pressed against the surface. Pressure on a handle automatically opens an internal radiation shield and activates the testing mechanism. When the test is complete, the LCD will display the value of the lead directly in milligrams of lead per square centimeter (mg/cm^2) of surface. The amount of time to perform a test varies with the age of the radioactive source and ranges from 10 to 15 seconds when the source is new, to 25 to 30 seconds when the source is a year old. The limited life of the source means that the source must be replaced annually. The unit must be returned to the manufacturer. Although the actual time necessary to replace the source is quite short, it is necessary to coordinate the replacement 1 or 2 months in advance so the manufacturer will have the source material available. The cost to replace the source and recalibrate the unit ranges from $1500 to $2000.

The radiation source is 10 microcuries (mCi) of ^{57}Co (cobalt-57). If used improperly, exposure to gamma radiation and X-rays could occur. Because the source is radioactive, the owner of the unit must have an Atomic Energy Commission license. A "wipe test" must be performed every 6 months (at a cost of about $20) to ensure the source is properly shielded.

Initial Evaluation of XRF Unit Accuracy

The NIST report evaluated the accuracy of the prototypes and the commercial version of the PGT XK-3. The report is based on a contract to develop a unit that has an accuracy of 0.2 mg/cm^2. Because the NIST work used samples having lead contents about 1 mg/cm^2, further testing was needed to ensure that the measurements were accurate in the 1 mg/cm^2 range and to determine if the accuracy held constant for the entire 10-mg range of the unit.

A series of tests on samples of known lead content were conducted to gauge the accuracy of the analyzer. To prepare standards with low lead levels, yellow lead oxide (PbO), was added incrementally by weight to a lead-free oil-base paint. For lead levels over about 4 mg/cm^2, TT-P-86 Type I red lead linseed oil paint was selected as a standard. This paint is pigmented solely with red lead oxide (Pb_3O_4). For each paint, the percent lead by weight of dry paint was calculated. To prepare a set of standards for evaluation, the paints were applied to chart papers to yield a range of thicknesses from 0 to greater than 10 mg/cm^2. The chart papers are lead free and uniform in weight per unit area. The true lead content of each sample was derived from the weight of paint per unit area of the chart paper. The results are shown in Table 1. Figure 2 is a graphical comparison of the results. Each data point represents the average of three readings. Figure 2 shows a correlation between measurements made with the XK-3 and the true lead content. The maximum reading on the unit is 10.0 mg/cm^2; measurements of lead contents over that amount will be given as 10.0. Measurements made by the XK-3 test unit consistently fall below the true lead content (Table 1 and Figure 2). Although a calibration curve or table can be constructed for the test instrument, the results would not necessarily be applicable to other lead analyzers, for which similar tests can be run.

Figure 1. The x-ray fluorescent lead analyzer.

Table 1

Measured and Actual Lead Content of Samples

Measured Lead Content	Actual Lead Content
0.0	0.0
0.1	0.0
0.2	0.0
0.3	0.1
0.4	0.2
0.5	0.4
0.6	0.5
0.7	0.6
0.8	0.8
0.9	0.9
1.0	1.0
1.2	1.3
1.4	1.6
1.6	1.9
1.8	2.1
2.0	2.4
2.2	2.7
2.4	3.0
2.6	3.2
2.8	3.5
3.0	3.8
3.2	4.1
3.4	4.3
3.6	4.6
3.8	4.9
4.0	5.2
4.2	5.4
4.4	5.7
4.6	6.0
4.8	6.3
5.0	6.5
5.2	6.8
5.4	7.1
5.6	7.3
5.8	7.6
6.0	7.9
6.2	8.2
6.4	8.4
6.6	8.7
6.8	9.0
7.0	9.3
7.2	9.5
7.4	9.8
7.6	10.1
7.8	10.4
8.0	10.6
8.2	10.9
8.4	11.2
8.6	11.5
8.8	11.7
9.0	12.0
9.2	12.3
9.4	12.6
9.6	12.8
9.8	13.1

Field Use of the XRF Unit

The PGT XK-3 unit was used in West Germany at more than 30 sites and many locations at each site. The unit was used daily with no malfunction. The battery pack maintained its charge for the entire day at a sufficient level so the time required for each reading did not change. A voltage converter was used to recharge the unit each night. Calibration was checked before use at each site and was satisfactory. However, recalibration was necessary after the unit had been used on extremely high lead level surfaces. In these instances, the recalibration procedure effectively restored the calibration.

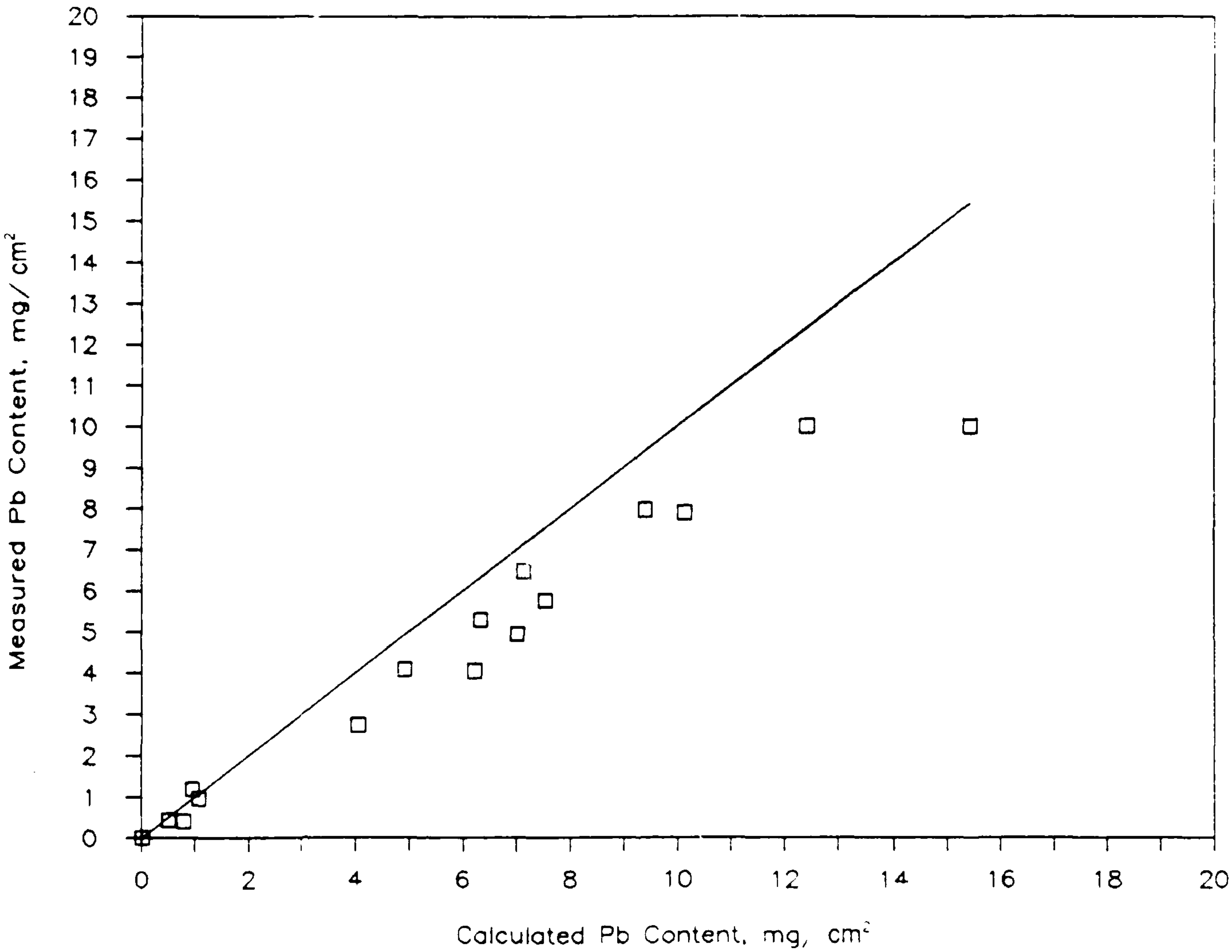

Figure 2. Measured vs. calculated lead content of samples.

At each location, three readings were taken within a several square centimeter area. (Results are recorded in the Appendix.) As noted in the NIST report, not all measurements were within ±0.2 of the mean. However, the readings were consistently within ±0.5 of the mean, which is the limit suggested by the instruction manual as criteria for checking the unit's calibration. Occasional variations beyond that limit could have been due to the fact that the readings were not made on exactly the same spot, and a slight change of location could expose a greater or lesser thickness of the lead bearing coating, thus affecting the results of the analysis.

Correction for Background Effects

Because the field measurements raised concern about further inaccuracies of the readings due to interference from the substrate or film thickness, testing was conducted to evaluate the effects of various substrates and the paint film thickness.

The test consisted of preparing a "free" film (not on a substrate) consisting of vinyl resin, plasticizer, lead oxide, and a small amount of carbon black pigment. The film was taped across the window of the XRF unit to ensure consistent exposure of lead. With the film in place, readings were taken over various substrates. Substrates included: lightweight concrete block, dense concrete brick, pine lumber, birch lumber (each 3.81 cm thick), and on 32 mil* and 58 mil steel, 32 mil aluminum, 1.27 cm drywall and 1.27 cm stucco. The stucco sample was belt sanded to produce a reasonably flat surface. Readings were also taken over the lead standard supplied with the unit (Table 2) and over each bare substrate without the free film of paint. The substrates were placed on 15.24 cm of polystyrene while measurements were taken to minimize any interference from the surface of the laboratory bench.

To check the effect of film thickness on lead readings, the instrument was again modified by placing 24 mil or 48 mil mylar sheets between the instrument window and the free film of lead. Readings were taken again on the various substrates. Tables 3 through 12 contain the readings for all these tests. Each column contains 14 separate readings; there is no horizontal correlation between columns. Table 13 is a composite of the calculated averages.

A PVC-formula paint film specimen was prepared for analysis by sequential oven drying, programmed dry-ashing, digestion in 1:1 nitric acid, and evaporation to the azeotrope. The digests were diluted to an appropriate volume for analysis. The lead concentration was determined by atomic absorption spectroscopy using a Perkin Elmer 3030B Atomic Absorption Spectrophotometer. The sample was 20.12 x 1.91 cm = 38.32 cm^2, 0.0068 ± 0.0005 cm thick, and weighed 0.34 g. It was dried in an oven for 8 hours at 110 °C. The sample was then dry-ashed in a furnace. The furnace temperature was increased from 100 to 450 °C over a 4-hour time span and was then held at 450 °C for 1 hour. The digest was 20 ml of 1:1 nitric acid which was evaporated to 5 ml. The digestion/evaporation process was repeated. Then the liquid was diluted to 250 ml with deionized water.

Large volatilization losses of lead during dry-ashing of polyvinyl chloride have been reported by Gorsuch[5] and attributed to the formation of lead chloride. Investigations of measures in the dry-ashing of biological and environmental material to minimize volatilization losses of metal halides[6] resulted in

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*1 mil = 0.00254 cm

[5] T.T. Gorsuch, *The Destruction of Organic Matter* (Pergamon Press, New York, NY, 1970), P. 34-35.

[6] R.S. Vogel, et al., *Lead in the Environment*, W.G. Boggess, Ed., 1976, Chapter 2, Part 1, prepared for the National Science Foundation, NSF/RA-770214.

programming the temperature rise of the furnace from 100 to 450 °C over 4 hours in an oxidizing atmosphere. This "temperature ramping" prevents flash burning; an oxidizing atmosphere allows conversion of existing lead halides to less volatile species while facilitating carbon removal at a lower temperature than the commonly used 500 °C.

The basic methodology for determining the lead concentration followed ASTM D3335-85a[7], with modifications in the drying and ashing steps as noted above. The sample was divided to run duplicate tests. Lead content in the specimens was 1.19 and 1.33 mg/cm^2. The sample weighed 8.87 mg/cm^2 and thus had a lead content of 14.2 percent by weight. For comparison, TT-P-104 typically contains 78 percent white lead carbonate pigment. Using the recommended spreading rates, this translates into approximately 27.5 mg/cm^2 of lead for a typical three-coat system. TT-P-104 probably represents the highest lead-containing paint. Other paints may have contained no "lead-base" primary pigments but still contain varying amounts of lead due to the lead driers and the use of color pigments containing small percentages of lead.

[7] ASTM D3335-85a, *Test Method for Low Concentrations of Lead, Cadmium, and Cobalt in Paint by Atomic Absorption Spectroscopy* (American Society of Testing and Materials [ASTM], 1985).

3 DATA ANALYSIS

Analysis of Field Data

The data from the field use of the unit are shown in the Appendix. Three readings were taken at each site. The correction factor was applied to each of the readings and the results were averaged to produce the corrected average value. The factor for the bare substrate, based on Tables 3 through 12, was subtracted from this corrected average to give the true lead level for the coating. In a few cases, the lead level could not be calculated because the background work to develop a factor for the particular substrate had not been conducted.

High lead levels (in excess of 1 mg/cm^2) were found in several locations. In State Department family housing in Frankfort, high levels were found in a bathroom of one housing unit (see page 27). Levels of about half this amount were found on a section of wood trim in the kitchen and on the walls of a bathroom in another unit in the same complex. Perhaps the high levels in the first bathroom reflect additional paint thickness compared to the kitchen trim and second bathroom.

The buildings at Camp King were constructed in the 1930's. Significant rehabilitation had not been done on any of the buildings visited. The IRS building had high lead levels on the first floor wall which probably reflects the use of a lead-base paint many years ago.

Lead levels for Camp King and at other locations occasionally were recorded as negative numbers (see page 28). Assuming the value is quite small (-0.1 to -0.2), it could be explained as being within the tolerance limits of the XRF unit. However, when values are larger (e.g., -0.5 to -0.6), the discrepancy must be the result of the correction factor for the substrate. In most cases where large negative results are recorded, the substrate was plaster. As mentioned earlier, masonry materials can exhibit a large variation in composition with the net result that the correction factor applied was inappropriate for the specific location. In future work, it may be necessary to establish a correction factor in the field specifically for that location.

In the Kaiserslautern area, a 20-year-old building was checked. This building had been remodeled about 3 years ago. The XRF unit revealed that the old portions of the building had high levels whereas the newer areas were less than 1 mg/cm^2. In the same area, an apartment was found to have high lead readings in hallways (see page 29).

Of all the sites evaluated in the Landstuhl, Heidelberg, and Munich (see pages 30 through 32) areas, one of the highest readings was on the lower portion of a hallway (see page 31). This was an entrance hall and stairway area in an apartment complex. The plaster on the lower area was thicker and was a different color from that on the upper portion of the wall. Readings were significantly different between the upper and lower portions of the wall. However, it is unknown if this variation was due to the alternative paint system or to the different background.

High lead readings were found in Armed Forces Recreation Centers in Garmish and Berchtesgaden (see page 33). In the Garmish center, these readings were in the bathrooms but not the bedrooms. In Berchtesgaden, high levels were in bedrooms (see page 32).

Analysis of Laboratory Data

Accuracy of XRF unit

As shown earlier (Table 1 and Figure 2) the measurements made by the XRF are consistently below the true lead content. The unit is quite accurate at the lower end of the scale but the accuracy decreases with increasing lead content in the paint.

Effect of Substrate

The data in Tables 3 through 12 show conclusively that the substrate has an effect on the XRF value. Readings on the bare substrates range from an average low of 0.15 mg/cm^2 for drywall to an average high of 1.15 mg/cm^2 for dense concrete. These calculated averages are the correction factors. The effect of the substrate must be subtracted from the unit reading to determine the true lead content of any applied paints. It is interesting to note that the values for pine (soft wood) and birch (hard wood) are essentially equal. Similarly, 32 mil and 58 mil steel have readings that are within experimental error of being equal. It should not be necessary to have different correction factors for readings taken on different types of woods or different thicknesses of steel. Conversely, masonry materials produced widely varied correction factors. It is therefore necessary to develop correction factors for each of these types of substrates. It should be pointed out that a single substrate sample was used for each series of results and all readings were taken on a single spot on that substrate. Because of the wide range of factors contained in various masonry substrates, additional work should be done to determine how these factors may vary from one source to another. Perhaps the correction factor for plaster will be significantly higher or lower based on the plaster's age, composition, or some other unknown variable.

A recent National Institute of Building Science report confirms that substrates have an effect on the instrument reading[8]. This report indicates that the substrates can be grouped by type and that concrete and gypsum board constitute a single type, all metal constitutes a single type, and all plaster is a single type.

The composite data (Table 13) shows lightweight concrete block to have a response of 0.42, dense concrete 1.15, and drywall (gypsum board) 0.15. There is also a significant difference between aluminum and steel substrates and it is believed that different plasters may provide different responses. Thus, substrate classification will not provide sufficient accuracy.

Effect of Distance Between XRF and Lead Source

Tables 3 through 12 also show the effect of placing two different thicknesses of mylar film between the detector window and the lead paint film. In all cases the mylar reduced the reading on the unit. Doubling the thickness of mylar fell slightly short of doubling the reduced reading. The reduced readings are caused by the distance created by the mylar and not by the composition of the mylar itself. Although this thickness factor appears to be significant, it would be very unusual to find 24 or 48 mil thicknesses of lead-free paint applied over an existing lead-bearing coating. A typical coating system containing five or six coats of modern lead-free coatings would measure less than 10 mils and its effect on the readings would be insignificant.

[8] *Lead-Based Paint Testing, Abatement, Cleanup and Disposal Guidelines* (National Institute of Building Science, March 16, 1989), pp 173-174.

Table 2

Readings With Lead Standard

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	1.9	2.4	2.4	2.3
	1.8	2.4	2.0	1.9
	1.1	2.6	2.2	1.7
	1.2	2.3	2.3	2.2
	1.7	2.5	1.8	2.9
	1.4	2.7	1.8	1.9
	1.3	2.5	2.7	2.2
	1.0	2.4	2.6	1.6
	1.5	2.4	2.8	2.3
	1.7	2.9	2.3	2.7
	1.3	2.8	2.2	2.1
	1.7	2.9	2.6	2.2
	1.4	2.5	1.8	2.1
	1.1	2.6	2.4	2.2
Average	1.44	2.57	2.27	2.16

Table 3

Stucco Substrate

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	1.0	1.8	1.7	1.0
	0.7	1.6	1.2	1.3
	0.7	1.1	1.5	1.5
	0.6	1.8	1.0	1.5
	0.9	1.4	1.3	1.2
	0.5	1.4	1.9	1.7
	0.4	2.0	1.2	0.8
	0.4	1.8	1.9	1.5
	0.7	1.3	1.4	1.4
	0.9	2.1	1.6	1.4
	0.3	1.2	1.8	1.0
	0.2	2.0	1.3	1.1
	0.5	1.9	1.6	1.3
	0.9	1.4	1.4	1.6
Average	0.62	1.63	1.49	1.38

Table 4

Drywall Substrate

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.2	1.0	1.3	1.2
	0.0	2.0	1.3	0.5
	0.2	1.8	1.4	1.1
	0.2	1.7	1.0	0.9
	0.5	0.9	1.6	1.2
	0.0	1.2	1.2	0.9
	0.1	1.1	1.1	0.8
	0.1	1.1	1.2	0.7
	0.0	1.2	1.0	1.2
	0.4	1.4	1.1	1.2
	0.3	1.2	1.0	0.7
	0.0	0.8	0.9	1.0
	0.1	1.1	1.1	0.9
	0.0	1.3	1.8	1.0
Average	0.12	1.27	1.21	0.95

Table 5

Pine Substrate

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.2	0.9	1.3	0.5
	0.2	0.9	0.7	0.9
	0.5	1.5	0.9	1.2
	0.1	1.2	1.4	0.8
	0.1	1.2	1.2	0.9
	0.3	1.3	1.4	0.4
	0.0	1.3	0.9	0.8
	0.4	1.9	0.9	0.6
	0.1	0.8	0.8	1.1
	0.0	1.4	0.8	1.3
	0.1	1.7	0.7	1.2
	0.2	1.0	1.5	0.6
	0.3	1.2	1.4	0.8
	0.3	1.3	1.0	0.8
Average	0.20	1.25	1.06	0.85

Table 6

Birch Substrate

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.2	1.5	1.3	0.8
	0.3	1.4	1.6	1.3
	0.1	1.8	1.4	0.7
	0.6	1.4	1.6	1.1
	0.1	1.2	1.4	1.2
	0.2	1.0	1.0	1.1
	0.9	1.7	1.2	1.1
	0.0	1.5	1.2	0.9
	0.4	0.8	0.8	1.6
	0.3	1.4	1.1	1.0
	0.4	1.5	1.1	1.3
	0.2	1.0	1.4	0.8
	0.2	1.1	1.2	1.2
	0.1	1.7	0.8	1.3
Average	0.19	1.43	1.22	1.17

Table 7

Aluminum (32 mil)

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.1	1.7	1.4	1.0
	0.3	2.1	1.6	1.3
	0.3	1.4	1.2	1.3
	0.1	1.3	1.4	1.2
	0.5	1.6	1.1	1.0
	0.2	0.9	0.8	1.2
	0.2	0.9	0.9	0.9
	0.2	1.4	1.1	0.8
	0.0	1.6	1.1	0.7
	0.2	1.3	1.0	1.4
	0.0	1.9	1.3	1.1
	0.6	1.4	1.2	0.7
	0.4	1.8	0.8	0.9
	0.0	1.5	1.8	1.1
Average	0.21	1.48	1.19	1.05

Table 8

Steel Substrate (32 mil)

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.8	2.3	1.3	1.6
	1.0	1.8	1.4	1.7
	0.2	1.8	1.6	1.1
	0.8	1.6	1.0	1.0
	0.6	1.5	1.5	1.8
	0.6	2.1	1.2	1.6
	0.4	1.8	1.2	1.1
	0.6	2.0	1.8	1.7
	0.7	2.1	1.6	1.0
	1.1	1.5	1.6	1.5
	0.9	2.4	1.5	1.0
	0.1	2.1	2.0	1.3
	0.4	2.2	1.5	1.5
	0.9	1.8	1.1	1.6
Average	0.65	1.93	1.45	1.39

Table 9

Steel Substrate (58 mil)

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.1	1.4	1.5	1.5
	0.4	1.2	1.5	2.0
	0.7	2.0	1.3	1.6
	0.6	2.1	1.9	1.5
	1.4	2.6	1.5	1.2
	0.9	1.9	1.7	1.5
	0.7	2.1	2.0	1.7
	0.4	2.4	1.6	1.3
	0.9	1.8	1.9	1.3
	0.4	1.8	1.0	1.4
	0.2	1.9	1.8	1.8
	0.6	1.7	1.5	1.1
	0.7	2.4	2.0	1.6
	0.7	2.1	1.6	1.4
Average	0.62	2.0	1.63	1.49

Table 10

Lightweight Concrete Block Substrate

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.3	1.5	2.0	1.3
	1.2	2.0	1.3	1.3
	1.0	1.6	1.3	1.5
	1.1	1.8	1.5	1.2
	0.5	1.8	1.7	1.2
	0.4	1.9	1.2	1.4
	0.6	1.6	1.2	1.3
	0.8	1.8	1.3	1.4
	0.8	1.3	1.7	1.3
	0.6	1.4	1.0	1.3
	0.0	2.0	1.6	1.3
	0.1	1.9	1.5	1.4
	0.2	1.9	1.5	1.2
	0.9	1.7	1.6	1.4
Average	0.42	1.73	1.45	1.31

Table 11

Dense Concrete Substrate

	Bare Substrate	Substrate + Lead film	Substrate + Lead film + 24 mil Mylar	Substrate + Lead film + 48 mil Mylar
	0.4	2.4	2.1	2.2
	1.1	2.7	2.0	1.7
	1.0	2.0	2.0	1.9
	1.0	2.3	2.0	1.4
	1.7	2.4	2.0	2.0
	1.0	2.5	1.6	2.2
	1.0	2.6	2.0	1.7
	1.3	2.6	2.0	1.4
	1.4	2.7	1.9	1.3
	0.4	2.5	2.4	2.0
	1.7	2.5	1.7	2.1
	0.6	2.1	2.2	1.8
	1.4	1.9	1.5	1.7
	2.1	2.4	2.0	1.9
Average	1.15	2.4	1.96	1.82

Table 12

Plaster Substrate

	Bare Substrate
	0.7
	0.4
	0.8
	1.1
	0.5
	1.3
	1.0
	0.6
	0.5
	0.9
	0.8
	0.6
	0.5
	0.8
Average	0.75

Table 13

Composite of Test Results

	Bare Substrate (A)	Substrate + lead film (B)	Substrate + lead film + 24 mil Mylar (C)	Substrate +lead film + 48 mil Mylar (D)	Calculated lead mg/cm^2 (B-A)	Loss due to 24 mil Mylar (B-C)	Loss due to 48 mil Mylar (B-D)
Stucco	0.62	1.63	1.49	1.38	1.01	-0.14	-0.25
Drywall	0.15	1.27	1.21	0.95	1.12	-0.06	-0.32
Pine	0.20	1.25	1.06	0.85	1.05	-0.19	-0.40
Birch	0.19	1.43	1.22	1.17	1.24	-0.21	-0.26
Aluminum, 32 mil	0.21	1.48	1.19	1.05	1.27	-0.29	-0.43
Steel, 32 mil	0.65	1.93	1.45	1.39	1.28	-0.48	-0.54
Steel, 58 mil	0.62	2.00	1.63	1.49	1.38	-0.37	-0.51
Lightweight Concrete Block	0.42	1.73	1.45	1.31	1.31	-0.28	-0.42
Dense Concrete	1.15	2.40	1.96	1.82	1.25	-0.44	-0.58
Plaster	0.75						
Lead Std (1.51)	1.44	2.57	2.27	2.16	1.41	-0.30	-0.69
Average					1.24	-0.28	-0.44

Scatter of Individual Readings

Although the overall accuracy of the unit is excellent after many numbers are averaged, the reliability of any individual reading is open to question. Accuracy of the unit of ± 0.2 as indicated by the NIST report is true for only 65 percent of the readings; however, accuracy of ± 0.5 as indicated by manufacturer's literature is true for over 97 percent of the readings.

Analyses of the results shows that the standard deviation (σ) is approximately 0.3. A 95 percent upper confidence limit can be calculated as:

$$\bar{x} \pm 1.96 \left(\frac{\sigma}{\sqrt{n}}\right)$$

where $\bar{x}$ = the average reading,
n = the number of readings taken,
σ = the standard deviation.

By solving this equation for n, it is found that to have 95 percent confidence of an average of readings being within ± 0.1 of the true value, 35 readings must be taken; ± 0.2 requires 9 readings and ± 0.3 requires 4 readings. Similarly, ± 0.1 at 80 percent confidence can be obtained with 15 readings and 99 percent confidence with 60 readings.

XRF Comparison With Current Practice

Nellingen Barracks had already initiated efforts to determine the lead content of the paint on walls at the installation. It was apparent that a screwdriver, or similar tool, had been used to remove samples from the wall. Each sample left a hole in the plaster approximately 0.04 cm deep and 2.54 to 5.08 cm square. Atomic absorption was reportedly used to analyze samples. However, information regarding sample preparation or test conditions was not available.

The installation intended to completely strip all paints from walls having more than 0.06 percent lead in the paint. In one room, wall samples taken 61 cm apart had reported lead contents of 0.578 percent and 0.365 percent. The XRF unit indicated lead levels in the 0.7 to 0.9 mg/cm^2 range adjacent to these two sites as well as on other random locations along the wall. In another room, two samples had been taken about 30.5 cm apart having reported lead contents of 0.198 percent and 0.033 percent respectively. The XRF unit produced a value of -0.5 mg/cm^2 adjacent to these sample units and randomly along the wall.

4 DISCUSSION OF RESULTS

Scale Correction

Evaluation of the test instrument revealed that readings of lead levels fell below the actual lead content over the majority of the scale. Graphing the results produces a line passing through 1 for 1 mg of lead to a reading of 10 mg/cm^2 (the maximum for the unit) at an actual lead concentration of over 12 mg/cm^2. Although no effort was made to check additional instruments to find if this deviation is consistent for all PGT XK-3s, it indicates an inaccuracy of the readout with the specific unit. Therefore a calibration curve should be developed for each unit upon procurement or after installation of a new source. If the test instrument is typical of all units, it may not be necessary to apply a scale correction factor to assess compliance with the HUD requirement of 1 mg/cm^2 max unless other factors, such as background readings for some substrates, raise the scale readings.

General Equipment

The unit is mechanically durable and performed satisfactorily in all of the laboratory and field evaluations. It is easy to operate and, if used according to the instructions, is quite safe. However, the high initial cost, annual cost of replacement of sources, the atomic energy licensing and semiannual wipe test requirements, as well as the potential hazards that might be associated with misuse of the x-ray unit make routine purchasing of these units by installations a questionable practice. A more cost effective approach might be to contract this work.

Test Procedures

Analysis of the data shows that the XRF scale readings do not show the true lead level throughout the entire scale range. The results do, however, follow a straight line. It is not known if this straight line produced with one test instrument would be identical for similar instruments nor if the line would change with the annual replacement of sources and factory recalibration. For these reasons, it is concluded that the scale readings of each instrument should be checked with at least two standard lead level sources to determine the slope of a standardization curve for the instrument. Once this is established, checking the instrument on a single standard before each use as recommended by the manufacturer will be sufficient to ensure reproducibility.

A correction factor for the substrate must be subtracted from the instrument reading to determine the amount of lead in the coating. This basic conclusion is confirmed by the NIBS report. It is necessary to be quite specific when determining the background reading to select a substrate that is virtually identical to that over which actual measurements are to be taken. All metals do not produce the same background reading, all concretes do not produce the same background reading, and it is suspected that all plasters do not produce the same background reading. Minimal work with steel does, however, indicate that thickness has no effect on the readings. This may be true for other substrates.

Because a layer of lead-bearing paint hidden by a thickness of mylar will yield lower readings relative to the thickness of the mylar, heavy layers of paint will likewise reduce the readings of a hidden coat of lead bearing paint. The reduction due to 24 mils of mylar was -0.28 mg/cm^2. It would be very uncommon to find an instance where a lead bearing paint was covered by such a great thickness of

additional coating. (Such coatings would probably be exhibiting catastrophic failure due to internal stress within the paint system.) Thus, when taking field measurements, the effect of coating system thickness can be overlooked as insignificant.

The scatter of the individual readings provided by the test unit is greater than that implied in the NIST report; however, the scatter can still be satisfactorily assessed by evaluating the data statistically. As shown in Chapter 3, four data points will provide a 95 percent confidence level of $\pm$ 0.3 mg/cm^2. Taking measurements at this rate should be satisfactory for conducting a survey of a large number of buildings on an installation. In specific locations where greater accuracy is necessary to determine the need for abatement, additional readings could be taken to increase the level of confidence.

Under laboratory conditions, results of measurements taken with the XRF unit are essentially equal to the results obtained by atomic absorption. However, under field conditions, the results of the atomic absorption will be greatly affected by the sampling and sample preparation procedures while the XRF results will only be affected by variations in the substrate. This was demonstrated at a field location where atomic absorption samples were taken 30.5 cm apart on a wall. The results varied in lead content by a factor of six, while the XRF unit indicated a relatively uniform reading across the entire wall, including areas immediately adjacent to the atomic absorption sampling sites. Because atomic absorption analysis is based on weight, it is critical that all particles of substrate be removed from the paint sample. Similarly, because coatings containing lead are probably the oldest coatings on a wall, it is critical that all traces of the initial coat of paint are removed from the substrate. Accomplishing both of these objectives simultaneously is extremely difficult and probably lead to the varied results.

Use of Lead-Bearing Paints in West Germany

There is no evidence of paints with a large lead content being routinely applied in family housing units in West Germany, although lead concentrations in excess of the HUD limit were found in given areas of a number of units. The areas included bathroom walls, apartment hallways, and other areas where more durable coatings may have been applied, and in older areas of one building. It cannot be said that all areas with durable coatings have high lead content nor can this be said about all older buildings. The problem is random and probably reflects liberal purchasing or quality control procedures on previous painting contracts. If abatement becomes required through regulations having limits similar to the current HUD requirements, abatement expenses may be limited; however, the detection effort will have to be extensive. The need for abatement may be determined by whether one or two coats of a lead-bearing paint was applied to a wall or whether even a single coat of high lead content paint was applied to an older area of a given building.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The XRF lead detector was found to be a very reliable instrument. There were no problems with field durability and the results obtained by using the machine unit readings with the correction factor were accurate. Field measurements are probably more accurate using the XRF than those obtained using atomic absorption methods due to difficulties in obtaining and preparing samples for the latter instrument. However, several factors must be taken into account when making XRF measurements:

1. The instrument scale may not be accurate over the entire range. This can be determined and compensated for by taking standardization readings at two different lead levels.

2. The substrate has a profound effect on the instrument reading. This must be compensated for by taking a standardization reading for each type of substrate that will be encountered. Due to the nonuniformity of plasters, concrete, and other masonry products, field standardization on these materials is desirable.

3. Lead-base paint hidden by layers of nonlead paint can be detected and accurately measured without compensation for coating thickness.

4. A scatter of individual readings does occur; however, application of statistics to the results proved that accurate results can be obtained using a limited number of readings.

There does not appear to be a large amount of existing lead-base paint on U.S. facilities in West Germany. The presence of the lead is random. If abatement becomes an Army policy, it is anticipated that the detection effort will have to be quite extensive; however, the actual abatement costs will not be large.

Recommendations

Although the PGT XK-3 XRF lead detector was practical and accurate, it is recommended the conclusions of this study be confirmed using other XRF units due to the factors discussed above. It is also recommended that the Army adopt a lead concentration level above which abatement must be accomplished. The lead concentration should be consistent with the already existing HUD requirement. A firm policy of lead detection and abatement should be developed and the DEH should be assisted in complying with the policy with appropriate funding and the development of a guide specification for the work.

APPENDIX:

Field Data from West Germany

Specific Description	I = Interior E = Exterior	Substrate	Readings*			Corrected** Avg.	Factor+	Lead++ Level
<u>Frankfort, HQ V Corps</u>								
Abrams Building								
Window Sill	I	Marble	.6	.7	.8	.63	---	---
Wall	I	Plaster	.7	.8	1.1	.85	.75	.10
Elevator Shaft	I	Wood	.3	.1	.1	.03	.20	-.17
The Terrace Club								
Door	I	Wood	.8	.7	.8	.73	.20	.53
Stairs	I	Steel	.7	.9	.8	.77	.65	.12
Central Education Center								
Wall	E	Stucco	1.3	.9	.6	.95	.62	.33
Wall	I	Plaster	1.1	1.4	1.4	1.45	.75	.70
Guard Shack								
Wall	E	Brick	.3	1.1	1.4	.95	---	---
Window Sill	E	Concrete	1.0	1.2	.8	1.03	1.15	-.12
Idle Hours Theater								
Wall	E	Concrete	1.1	.7	1.1	.97	.42	.55
Nursery								
Wall	E	Stucco	1.0	1.3	1.0	1.15	.62	.53

Boiler House								
Wall	E	Stucco	.5	.6	.9	.60	.62	-0.2
Family Housing (Constructed mid 1950's)								
Wall	E	Stucco	.6	.6	1.0	.67	.62	.05
Transient Housing								
Hall (lower area)	I	Plaster	.9	.9	1.5	1.18	.75	.43
Hall (upper area)	I	Plaster	1.3	1.4	.8	1.28	.75	.53
Family Housing								
Door Frame	I	Steel	1.3	1.6	1.6	1.75	.65	1.10
Frankfort State Dept.								
Family Housing	I	Plaster	.8	.9	.8	.80	.75	.05
Wall (living room)	I	Plaster	.8	.8	.5	.70	.75	-.05
Wall	I	Plaster	.4	1.0	.7	.60	.75	-.15
Wall (bathroom)	I	Plaster	1.7	2.7	1.9	2.53	.75	1.78
Wall (bathroom)	I	Plaster	1.7	1.3	1.9	1.90	.75	1.15
Wall (bathroom)	I	Plaster	2.1	1.6	1.5	2.07	.75	1.32
Door Frame (bathroom)	I	Wood	.2	.4	.5	.20	.2	0.00
Wall (kitchen)	I	Plaster	.5	.6	.6	.47	.75	-.28
Cabinet (kitchen)	I	Wood	.6	.5	.5	.44	.20	.24
Trim (kitchen)	I	Wood	1.1	.8	1.3	1.13	.20	.93
Wall (#2 bathroom)	I	Plaster	1.3	1.3	1.4	1.50	.75	.75
Window Opening	I	Plaster	1.3	.8	9.0	1.05	.75	.30
Wall (bedroom)	I	Plaster	.7	.8	.5	.6	.75	-.15
Wall (entry)	I	Plaster	.7	.8	.5	.6	.75	-.15

<u>Frankfort Camp King</u> (constructed in the 1930's)								
Timber Building								
Wall	I	Plaster	1.7	1.6	.8	1.57	.75	.82
Wall	I	Plaster	.4	.9	1.5	.95	.75	.20
Formal HQ Building								
Hall (lower portion)	I	Plaster	1.0	.6	.6	.83	.75	.03
Hall (lower portion)	I	Plaster	1.3	1.0	1.1	1.20	.75	.45
Wall (kitchen)	I	Plaster	1.4	1.3	1.2	1.5	.75	.75
Wall (basement)	I	Gloss paint	1.6	1.2	1.2	1.98	.75	1.23
Structural Member (2nd floor)	I	Wood	.4	.5	.5	.33	.20	.13
Wall (2nd floor)	I	Plaster	.2	.5	.3	.21	.75	-.54
Wall	I	Plaster	.9	1.0	.8	.9	.75	.15
Wall	E	Stucco	.5	.6	.5	.43	.62	-.19
<u>IRS Building (Formerly family house)</u>								
Wall	I	Plaster	1.4	1.6	1.9	1.92	.75	1.17
Berlin Stove	I	Ceramic	10.0	10.0	10.0	10.0	---	---
Wall (2nd floor bath)	I	Plaster	1.7	.8	1.1	1.32	.75	.57
Horse Barn								
Exterior	E	Stucco	.4	.9	.2	.37	.62	-.25
<u>Nellingen Barracks Stuttgart, VII Corps</u>								
<u>Child Development Center #3765</u>								
Hallway	I	Plaster	.9	.8	1.0	.9	.75	.15
Site #13 (room)								
wall -lower area	I	Plaster	.8	.7	.1	.47	.75	-.28
-upper area	I	Plaster	.5	0	.3	.17	.75	-.58
Window Sill	I	Wood	.7	.2	.3	.23	.20	.03
Cabinet	I	Wood	.8	1.1	.9	.95	.20	.75
Site 10 Room #4	I	Plaster	1.8	.9	1.2	1.43	.75	.68

Site 11	I	Plaster	1.1	1.8	1.4	1.62	.75	.87
Site 5	I	Plaster	.4	0	.5	.20	.75	-.55
Site 4	I	Plaster	.4	.5	.3	.23	.75	-.52
Robinson Barracks								
Hallway	I	Plaster	.7	.1	.7	.40	.75	-.35
Kitchen	I	Plaster	1.2	1.2	.5	1.00	.75	.25
Kitchen	I	Plaster	.7	.6	.2	.37	.75	-.38
Kitchen	I	Plaster	.4	.8	.6	.50	.75	-.25
Bathroom	I	Plaster	.6	.5	.5	.43	.75	-.32
Living Room	I	Plaster	.2	0	.7	.20	.75	-.55
Basement	I	Plaster	.7	.7	.8	.67	.75	-.08
Basement	I	Wood	.4	.4	.1	.13	.20	-.07
Wall	E	Concrete	.7	.7	.6	.57	.42	.15
<u>Kaiserslautern Area</u>								
Wierhof								
Living Room	I	Plaster	1.0	.7	.5	.67	.75	-.08
Bedroom #1 Wall	I	Plaster	1.4	1.0	1.0	1.20	.75	.45
Bedroom Wall	I	Plaster	.7	1.3	.5	.82	.75	.07
Bedroom Ceiling	I	Drywall	.6	.1	.4	.23	.15	.08
Kitchen	I	Plaster	.7	.7	1.2	.83	.75	.08
Bedroom #2	I	Plaster	1.2	1.2	1.0	1.20	.75	.45
Bedroom	I	Plaster	1.3	.4	1.5	1.13	.75	.38
Bedroom #3	I	Plaster	1.3	1.4	1.8	1.72	.75	.97
Door Frame	I	Galv	3.0	3.2	3.1	3.95	---	---
Door	I	Steel	.6	.7	.6	.53	.63	-.1
Living Room Ceiling	I	Drywall	.2	0	.6	.17	.12	.05
Hallway	I	Drywall	.8	.4	.6	.50	.12	.38
#2 Apartment								
Living Room	I	Plaster	1.5	1.2	1.0	1.35	.75	.60
Exterior	E	Stucco	1.2	1.1	.9	1.12	.62	.50

Elementary School Building - 20 years old #3994								
Repaired Area Hall	I	Plaster	2.1	2.4	2.1	2.70	.75	1.95
Original Hall	I	Plaster	2.8	2.7	3.1	3.63	.75	2.88
Hall	I	Plaster	3.0	2.7	2.8	3.55	.75	2.80
Hall (new construction 3 yrs old)	I	Plaster	1.4	1.4	1.5	1.65	.75	.90
Hall (old)	I	Plaster	2.9	2.[illegible]	2.2	3.22	.75	2.47
Office (3 yrs old)	I	Plaster	1.3	1.5	1.5	1.65	.75	.90
Child Development Center (Prefab Building) Bldg 4000	I	Drywall	.6	.1	.1	.17	.12	.05
Apartment Building #3996								
Hall	I	Plaster	1.7	2.1	1.6	2.15	.75	1.40
Hall	I	Plaster	2.2	1.4	1.4	1.97	.75	1.22
<u>Keleber Kasern</u>								
Childcare Center (80-90 yr old building)								
Hall	I	Plaster	0	.8	.2	.27	.75	-.48
Hall	I	Plaster	1.0	.6	.2	.50	.75	-.25
Cabinets	I	Wood	.1	0	.4	.07	.20	-.13
Exterior	E	Stucco	.6	1.4	1.0	1.03	.62	.41
Exterior	E	Stucco	1.2	1.1	.8	1.08	.62	.46
Playground Equipment	E	Wood	.2	.1	0	0	.20	-.20
<u>Landstuhl</u>								
Childcare Center #3812 (40 yrs old)								
Hall	I	Plaster	.4	.1	.2	.07	.75	-.68
Stairwell (upper area)	I	Plaster	1.2	1.0	1.2	1.20	.75	.45
Stairwell (lower area)	I	Plaster	1.2	1.3	1.7	1.58	.75	.83
Basement Wall	I	Plaster	.8	1.2	1.1	1.08	.75	.33
Basement Lounge	I	Plaster	.8	1.2	1.1	1.08	.75	.33

Basement Lounge	I	Plaster	1.6	1.0	1.4	1.50	.75	.75
Kitchen	I	Plaster	1.2	1.3	.9	1.22	.75	.47
Metal Door	I	Steel	.5	.3	.7	.37	.65	-.38
Wall (upper area)	I	Plaster	1.1	.4	.8	.72	.75	-.03
Wall (lower area)	I	Plaster	1.0	.5	.5	.73	.75	-.02
Playground Equipment	E	Wood	.6	.1	.2	.17	.20	-.03
Hiedelberg Romerster 1580 Bldg 3710 (Officer's House)								
Kitchen	I	Plaster	1.6	1.3	1.1	1.50	.75	.75
Kitchen	I	Plaster	1.1	1.0	1.2	1.15	.75	.40
Study	I	Plaster	1.2	.9	1.6	1.37	.75	.62
Study	I	Plaster	2.0	.7	1.5	1.58	.75	.83
Bathroom	I	Plaster	1.3	1.0	1.4	1.35	.75	.60
Bathroom	I	Plaster	1.8	1.2	.9	1.67	.75	.92
Bathroom Door	I	Wood	.8	.2	.8	.53	.20	.33
Bedroom	I	Plaster	.6	.5	.9	.60	.75	-.15
Family Room	I	Plaster	1.0	.7	.8	.80	.75	.05
Mark Twain Village Bldg 3651 Apartment								
Living Room	I	Plaster	.7	.4	1.1	.65	.75	-.10
Dining Area	I	Plaster	.8	.8	.7	.73	.75	-.02
Bedroom	I	Plaster	.2	.6	.7	.37	.75	-.38
Kitchen	I	Plaster	.5	.5	1.0	.60	.75	-.15
Hallway	I	Plaster	1.4	1.3	.8	1.28	.75	.53
2nd Apartment								
Living Room	I	Plaster	.9	1.1	.9	.98	.75	.23
Kitchen	I	Plaster	1.0	.9	.8	.90	.75	.15
Mark Twain Village Bldg 3710								
Living Room	I	Plaster	1.0	.9	.1	.63	.75	-.12
Kitchen	I	Plaster	.3	.7	.3	.27	.75	-.48
Bedroom	I	Plaster	.8	.4	.7	.53	.75	-.22

Hall (lower area)	I	Plaster	1.8	1.4	1.8	1.93	.75	1.18
Hall (upper area)	I	Plaster	.6	.8	.7	.63	.75	-.12
Patrick Henry Village								
Bedroom	I	Plaster	1.8	1.4	1.3	1.72	.75	.97
Bedroom	I	Plaster	1.3	1.3	1.2	1.40	.75	.65
#2 Bedroom	I	Plaster	.9	.9	1.2	1.03	.75	.28
Doorway	I	Wood	.6	.7	.5	.50	.20	.30
Hall (gray bottom)	I	Plaster	1.3	1.3	1.2	1.40	.75	.65
Hall (yellow top)	I	Plaster	1.2	.7	1.1	1.02	.75	.27
Living Room	I	Plaster	1.4	1.4	.6	1.23	.75	.48
Bedroom	I	Plaster	1.4	1.4	.8	1.33	.75	.58
Bedroom	I	Plaster	1.0	.8	1.3	1.08	.75	.33
Bedroom	I	Plaster	1.0	1.0	.8	.90	.75	.15
Bathroom	I	Plaster	1.2	.6	.7	.80	.75	.05
Building 4490								
Kitchen	I	Plaster	1.4	.8	1.4	1.33	.75	.58
Living Room	I	Plaster	1.1	1.0	.9	1.02	.75	.27
Bath	I	Plaster	1.5	1.3	1.7	1.73	.75	.98
Bedroom #1	I	Plaster	.9	.8	1.1	.95	.75	.20
Hall (lower level)	I	Plaster	1.0	1.2	1.0	1.10	.75	.35
Bedroom #2	I	Plaster	.9	1.0	1.0	1.00	.75	.25
Housing Unit								
Living Room	I	Plaster	.8	1.4	1.0	1.13	.75	.38
Kitchen	I	Plaster	1.1	1.0	1.1	1.10	.75	.35
Bedroom #1	I	Plaster	1.2	1.5	1.8	1.72	.75	.97
Bathroom	I	Plaster	.8	.5	.9	.70	.75	-.05
Bedroom #2	I	Plaster	1.2	.5	.8	.83	.75	.08
Housing Unit								
Kitchen	I	Plaster	1.5	1.0	1.5	1.50	.75	.75
Dining Area	I	Plaster	1.2	1.3	.9	1.22	.75	.47

Bath	I	Plaster	.5	1.6	.9	1.07	.75	.32
Marble Window Sill	I	Marble	1.2	1.6	.13	---	---	---
McGraw Kaserne, Munich								
Living Room	I	Plaster	1.1	2.0	1.4	1.72	.75	.97
Living Room	I	Plaster	.7	1.4	1.4	1.27	.75	.52
Bathroom	I	Plaster	1.1	1.2	1.6	1.45	.75	.70
Bedroom	I	Plaster	1.2	1.6	1.3	1.55	.75	.80
Door	I	Wood	.1	.3	.8	.3	.20	.10
Hall	I	Plaster	1.2	1.1	1.4	1.35	.75	.60
Armed Force Recreation Center - Garmish Abrams Complex								
Bedroom #1	I	Plaster	.9	1.6	1.5	1.52	.75	.77
Bedroom #2	I	Plaster	1.2	1.4	1.0	1.30	.75	.55
Bathroom	I	Plaster	2.1	2.2	2.4	2.75	.75	2.00
Bathroom	I	Plaster	2.1	1.9	1.9	2.35	.75	1.60
General Walker Hotel - Berchtesgaden								
Bedroom #1	I	Plaster	2.1	1.8	1.5	2.13	.75	1.38
Bedroom #1	I	Plaster	1.6	1.9	1.6	2.02	.75	1.27
Bedroom #2	I	Plaster	1.0	1.3	1.3	1.30	.75	.55
Door Frame	I	Wood	1.2	1.4	1.4	1.50	.20	1.30

* Readings = Triplicate instrument readings
** Corrected Average = The three readings were corrected using Table 1 and the results were averaged.
\+ Factor = Correction factor for the various substrates based on Composite Table
\+\+ Lead Level = Calculated lead based on Corrected Average - Factor

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